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ABSTRACT

This paper reports investigations of fairing configurations pointed toward substantially reducing hub drag. Experimental investigations have shown the importance of hub-fairing camber, lower-surface curvature, and relative size on the drag. The significance of pylon and hub fairings in combination have also been shown. Model test data presented here documented these findings, and also showed the effect of gaps and hub-fairing inclination angle on drag. From a drag standpoint, the best hub fairing had a circular arc, upper-surface curvature, a flat bottom surface, and 8.75% camber.

1.0 INTRODUCTION

Helicopter parasite drag has steadily decreased over the years. One of the largest reductions in drag has been the retraction of the landing gear. Also, improved construction techniques have enabled lightweight, low-drag shapes to be used for the fuselage, pylon, and empennage assemblies. Contemporary helicopters have a relatively sleek look which provides performance benefits, as well as marketing attractiveness. Because the overall helicopter total drag has decreased, the rotor hub, the last major source of high drag, now accounts for 30-50% of the total drag (ref. 1). Therefore, to continue to achieve improved parasite-drag reduction and cruise efficiency, reduction of hub drag is vitally important.

NASA Ames Research Center has begun investigations into fairing configurations that would result in reductions in hub drag on the order of 50-80%. These investigations commenced with the concept that a cambered hub fairing with a flat lower surface may be the best for reducing hub drag because it could greatly reduce the profile drag and interference drag associated with unfaired hubs.

The purpose of this paper is to show how the cambered, flat lower-surface concept was derived, and to summarize the results of wind tunnel investigations involving this configuration concept.

2.0 DERIVATION OF THE CAMBERED HUB FAIRING

Historically, rotor hub fairings have been a body of revolution with radial cross sections that are symmetrical. This fairing is depicted in figure 1 where it is shown atop a fuselage.

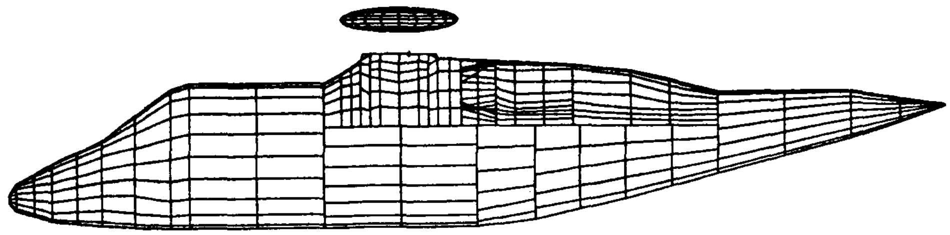

Figure 1 - Symmetrical hub fairing atop helicopter fuselage.

With a symmetrical hub fairing, the stream tube is a converging-diverging cross section in the region between the hub fairing and the fuselage. This converging-diverging flow results in considerable interference drag as inferred by the interference drag rise caused by the proximity of two adjacent airfoils which also have a converging-diverging stream tube between them. The study of adjacent airfoils was reported in reference 2. An example of the interference drag rise from reference 2 is presented in figure 2. A large portion of the interference drag results from the separated flow over the aft end of the airfoil surfaces that face each other.

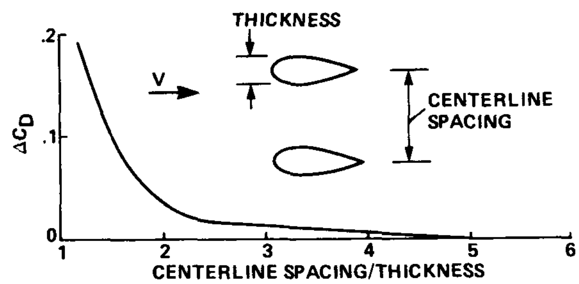

Figure 2 - Interference drag, ΔC_{D_O}, resulting from proximity of adjacent airfoils.

To eliminate the high interference drag, one solution would be to eliminate the converging-diverging boundary by flattening or straightening the surfaces that face each other, such as shown in figure 3. With the straight surfaces, it is hypothesized that the interference drag is lessened.

Applying this simple concept to a rotor hub fairing results in a hub fairing with camber and a flat lower surface. Modifying the symmetrical hub fairing to produce a flat lower surface has subtle geometric implications. This is illustrated in figure 4 for the case where a 24%

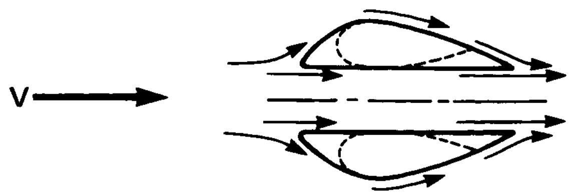

Figure 3 - Airfoils for minimum interference.

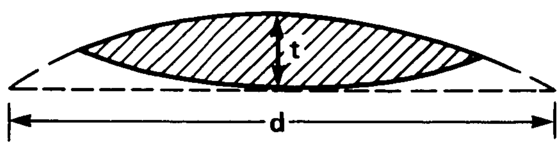

Figure 4 - Geometry from converting symmetrical fairing to cambered hub fairing.

t/d symmetrical circular-arc cross section is modified to produce a flat lower surface and the same upper-surface curvature. The main geometric result is a larger diameter with $t/d = 18\%$, frontal area increased 39%, and surface area increased 88%. Aerodynamically, this new configuration in free air would produce more lift because of its camber, and have greater drag than its counterpart symmetrical configuration. The larger drag would consist of more induced drag and greater skin friction and pressure drag. However, placed adjacent to a fuselage and/or a pylon, the configuration can produce benefits by favorably modifying or influencing nearby flow states or the flow state of the whole configuration.

This favorable effect was suggested by streamline investigations using a potential flow-panel method (ref. 3). A sample of the streamline investigation is shown in figure 5 for the symmetrical hub fairing over the fuselage and in figure 6 with the cambered hub fairing atop the fuselage. The streamlines from the symmetrical hub-fairing stream straight aft, whereas the streamlines from the cambered hub fairing go aft and down toward the fuselage. The streamlines from the symmetrical hub fairing appear to be independent of the presence and influence of the fuselage as if the hub fairing is a separate body. On the other hand, the streamlines from the cambered hub fairing are deflected down toward the fuselage, simulating closure of the flow about a body. The

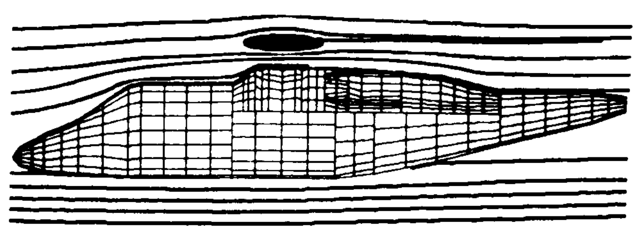

Figure 5 - Flow field about fuselage with symmetrical hub fairing.

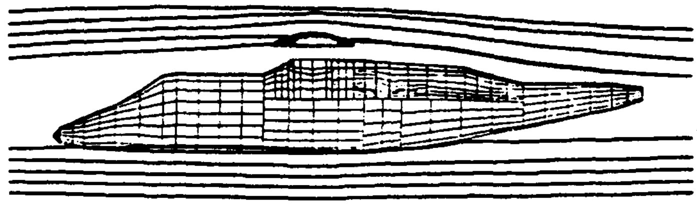

Figure 6 - Flow field about helicopter fuselage with cambered hub fairing.

streamlines appear to flow as if the hub fairing is an integral part of the fuselage and may be a favorable affect.

Rotor downwash may have an effect on design of the cambered hub fairing. The influence of rotor downwash is expected to be relative to a number of parameters such as height of the hub fairing above the fuselage, fairing diameter relative to fuselage width and contour of the pylon and fuselage ahead of and in the vicinity of the hub fairing.

To evaluate the potential drag reduction produced by the cambered hub fairing, a wind tunnel test program was conducted at Ames Research Center.

3.0 BACKGROUND

Two wind tunnel tests were conducted, one in 1985 and the other in 1986. Both tests used the XH-59A 1/5-scale fuselage model. The 1985 test (ref. 3) first evaluated the cambered hub fairing and found it to be very successful. The second test in 1986 (ref. 4) greatly expanded the evaluation of the hub fairing and pylon fairing configurations.

In the 1985 test, two nonrotating hub fairing shapes were evaluated; the cambered, flat lower-surface hub fairing and the symmetrical hub fairing (with the symmetrical hub fairing used as a standard for comparison). The symmetrical configuration was selected as the standard since it is representative of configurations previously investigated by researchers (refs. 1 and 5) in their quest for successful reduction of hub drag. Any new fairing developed under the NASA program must have much lower drag characteristics than the symmetrical fairing. Test results showed the cambered configuration had lower drag than the symmetrical configuration.

The cambered configuration was found to be effective whether or not a pylon was included as a fairing over the exposed simulated drive shaft and pitch control rods. This is shown in figure 7. It is rather interesting that the cambered, flat lower-surface fairing, when compared with the symmetrical fairing, produces greater drag reduction with a pylon fairing around the rotor drive shaft and control rods than without a pylon fairing.

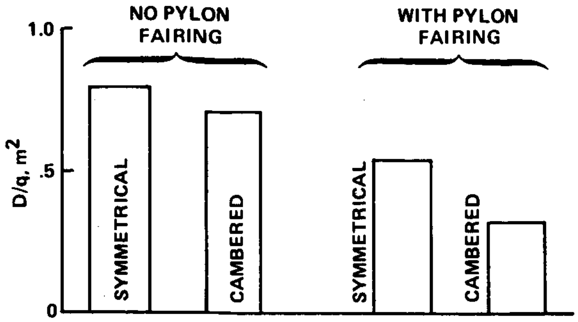

Figure 7 - Comparison of drag levels with symmetrical and cambered hub fairing.

Another finding from this test was that the configuration of the hub fairing influences the sensitivity of drag to pylon configuration. This substantiates findings of previous researchers (ref. 1) that hub fairing and pylon fairing are closely coupled by strong mutual interference effects.

The 1986 test was undertaken as a result of the effectiveness of the cambered hub-fairing concept. This test evaluated modifications of the concept for their effect on reduction in drag. In addition, since there is the strong mutual interference between the hub fairing configuration and the pylon configuration, tests included evaluation of various pylon configurations in conjunction with the hub fairings.

4.0 MODEL AND TEST CONDITIONS

The model used for evaluation of hub-fairing configurations was a 1/5-scale model of the XH-59A helicopter. This small-scale model served as only a test bed for generic hub-fairing investigations of single-rotor type helicopters. The centerline of the hub fairing was located at about one-half a fuselage diameter above the fuselage. This value was selected after a review of contemporary commercial single-rotor helicopters.

The model was sting-mounted to the external platform balance under the tunnel floor. The tests were conducted in the 7- by 10-Foot Wind Tunnels at Ames Research Center. Figure 8 shows the installation in the wind tunnel and the three components of the test hardware.

The data presented in this paper for each configuration were obtained from an angle-of-attack sweep from -8° to +2° and at a dynamic pressure of 3830 N/m^2 (80 lb/ft^2) for a unit Reynolds number of 5.4×10^6/m. Boundary-layer transition was not set on any configuration component. Model blockage was 2% and no corrections were applied to the data except sting tare corrections. Drag data are presented in relation to a full-size helicopter, that is, the model D/q was multiplied by 25 to obtain full-scale data.

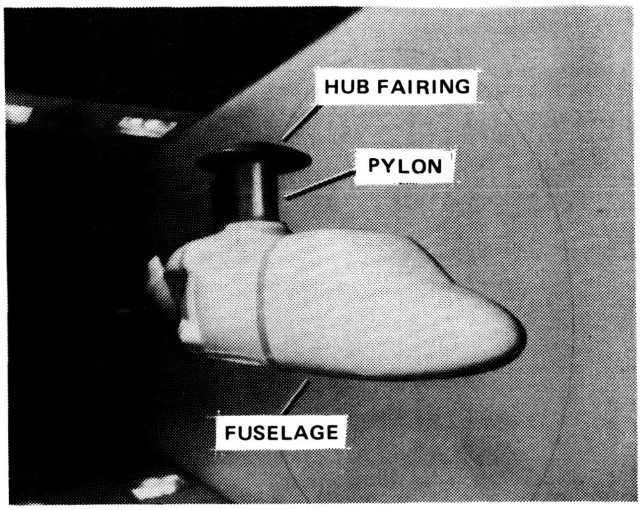

Figure 8 - Model installation in NASA Ames 7- by 10-Foot Wind Tunnel.

The hub fairings did not rotate during these tests. Nonrotating tests were selected because hub rotation was not essential to determine the aerodynamic performance between different hub fairings. That is, low-drag fairings nonrotating have been shown to be the low-drag fairings with hub rotation (ref. 6). Therefore, hub rotation was not essential to evaluate the cambered hub fairing compared to the symmetrical configuration. There is no doubt that hub rotation would be needed to determine the absolute drag level. Also, hub rotation is required to do a final evaluation with rotor-blade effects.

Test configurations discussed in this paper are:

1. Hub fairings with cross sections that varied from a symmetrical to a flat-bottom lower surface to concave lower surface.

2. Hub-fairing diameters that range from 1.23 times the pylon width to 3.13 times the pylon width.

3. Pylon cross sections that varied from faired, slab-sided shapes to NACA 0034 airfoil shape. A critical criterion in defining the pylon cross sections was the ability of the cross section to envelope a specified circular plate that simulated a swashplate and the rotating controls. Pylon cross sections included the center of the circular plate to be located from 20% to 56% of the pylon chord.

4. In addition, pylon and hub fairing configurations are included that enabled evaluation of various size gaps between the hub fairing and the pylon and enabled evaluation of shaft inclination.

The wind tunnel tests included numerous other hub-fairing and pylon-fairing configurations that are not included in this paper but are included in references 4 and 7.

5.0 INVESTIGATION OF HUB-FAIRING CONFIGURATIONS

Hub-fairing parameters that were varied were: camber, thickness-to-diameter ratio (t/d), and cross-sectional shape. Thickness-to-diameter ratios were varied from 0.13 to 0.33 and include t/d variation with either maximum thickness or diameter held constant as the other parameter was varied. Camber was varied from 0% (symmetrical) to 12% (reflex). Cross-sectional shape variations ranged from near rectangular to complex reflexed configurations. These shape variations were large compared to the minor shape variations caused by the camber and t/d variations. The hub fairing was mounted atop a pylon with a NACA 0034 airfoil for the cross-sectional shape. The side planform of the pylon was rectangular with a height above the fuselage of 0.41 fuselage effective diameters. Effective fuselage diameter is the diameter of a circle having the same cross-sectional area as the fuselage.

The effect of applying camber to two hub fairings, while holding t/d of each constant, is depicted in figure 9. The drag for fuselage alone, without pylon, is also included in figure 9 as a reference level. Fuselage angle of attack, α, is -2°. Camber is shown to have a major impact on drag. The data show that by adding 8.75% or more camber to a hub fairing with t/d = 18%, drag caused by the pylon and hub fairing can be reduced by 50%. Thickness-to-diameter ratio is a very important parameter which greatly affects how much drag reduction is attained by camber. With the thicker hub fairing, t/d = 24%, the benefit of adding cambering is amplified. With t/d = 24%, the $-\Delta D/q$ from adding 12% camber is doubled the $\Delta D/q$ from adding 11% camber to the hub fairing with t/d = 18%. From this study, it is quite evident that hub fairing camber has a major beneficial impact on drag.

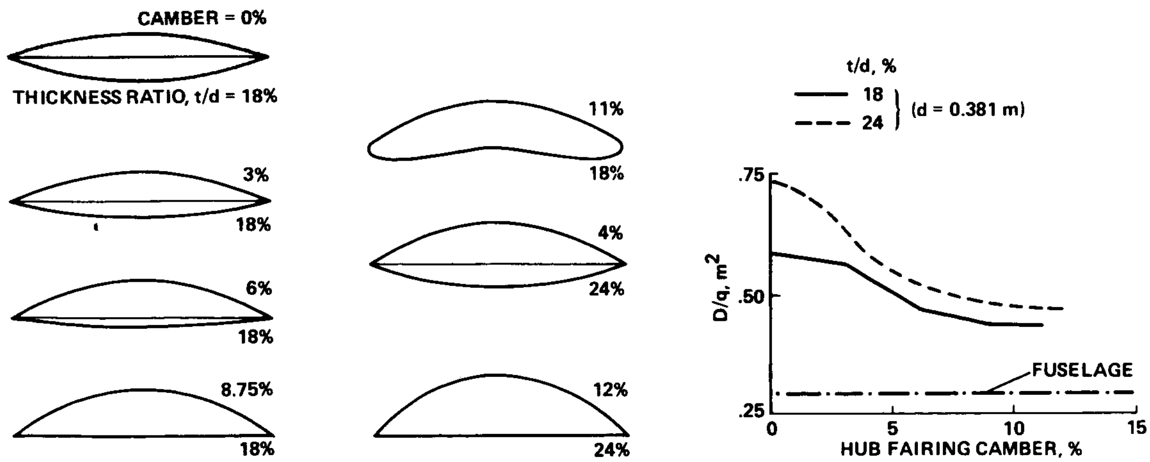

Figure 9 - Effect of hub-fairing camber on drag at α = -2°.

There are probably many mechanisms by which camber reduces the drag. The most obvious and straightforward mechanism is that the fairing's aft-facing bottom-surface area is reduced with increasing camber. Since the flow is separated in the region between the hub

fairing and the pylon, the smaller the aft-facing area on the hub fairing, the lower the drag. An additional mechanism is that cambering brings the hub fairing's bottom surface closer to the pylon edges. This in turn inhibits or eliminates formation of eddies shed from the top edges of the pylon.

Also evident from Figure 9 is an influence of camber on the sensitivity of the combined pylon and hub-fairing drag to hub-fairing t/d. Without camber, the drag of the pylon with the thicker hub-fairing combination is 52% greater than the drag of the pylon and thinner hub-fairing combination. By adding camber, that difference decreases rapidly. With about 11% camber, the thicker hub fairing results in only about 23% more drag. Thus, camber is seen to greatly reduce the adverse effects of increased hub-fairing thickness.

The effect of a broad range of hub-fairing t/d on drag is shown in figure 10 for hub fairings with flat lower surfaces. These data show that drag has a greater sensitivity to increased t/d when thickness is increased than when chord is decreased. This is because the decreased chord case results in decreased frontal area to the point where the hub fairing is almost a nub on the end of the pylon.

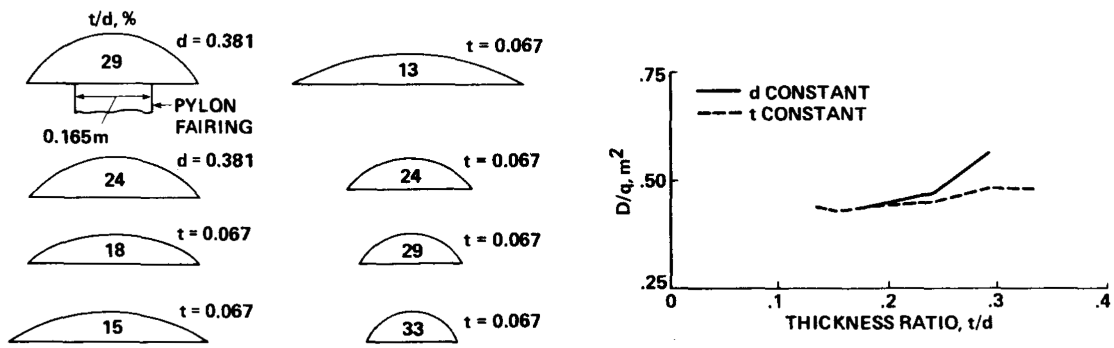

Figure 10 - Effect of hub-fairing thickness-to-diameter ratio on drag at $\alpha = -2°$.

Hub-fairing cross-sectional shape and its impact on drag is shown in figure 11 for both symmetrical and cambered, flat-bottom configurations. The cross-sectional shapes are classified by surface-curvature parameter, m, which is the second derivative of the thickness with respect to radial distance from the center. These data show the symmetrical and cambered hub fairing, with surface-curvature parameter $m = 0$, have about the same drag. This is probably because both have relatively flat upper and lower surfaces with considerable separation over their aft-facing lateral edges.

For the symmetrical configuration, the drag increased to a high level and is relatively insensitive to the changes in cross section with larger values of m. The increase in drag level from $m = 0$ to $m = -0.24$ is probably from two separate causes; 1) eddies from the top

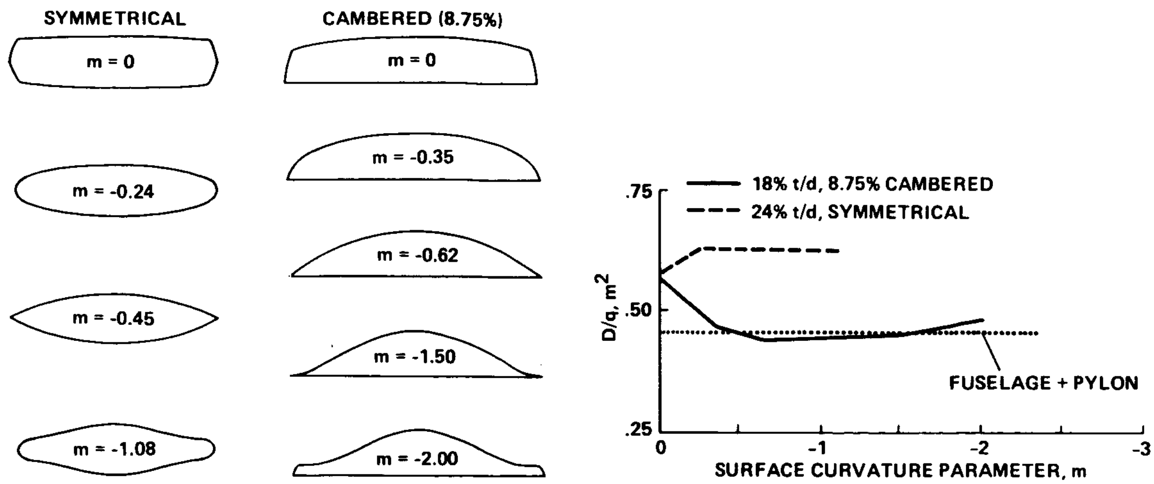

Figure 11 - Effect of hub-fairing cross-sectional shape on drag at $\alpha = -2°$.

edge of pylon, and 2) separated flow over most of the aft-facing surface area between the top of the pylon and the lower surface of the fairing geometry. The increase in drag from pylon edges should be relatively insensitive to these symmetrical hub-fairing configurations. The increase in drag from separated flow over aft-facing surfaces would be near equivalent for the elliptical and circular-arc configurations because they have about the same aft-facing surface area on the lower side facing the pylon. Although the reflexed configuration has less aft facing surface area than the other two configurations, its reflex results in a sizable space between the pylon lateral edge and the fairing surface. That space enables eddies to be shed from the pylon edges with an attendant increase in drag. Therefore, for the reflexed configuration the drag increase is from two sources, the separated flow over aft facing surface area and from eddies shed from the pylon lateral edges. For cambered, flat lower-surface hub fairings, the decrease in drag for larger magnitude of m is due to decreased frontal area and better upper-surface contouring for m to -0.62. The rise in drag for m from -.062 to -2.0 is because of the progressively smaller radii contouring of the upper surface. This effect is undoubtly overshadowing the influence of decreased frontal area.

6.0 INFLUENCE OF BLADE SHANKS

Exploratory investigations were made regarding blade shanks attached to the hub fairings to account for the blade hardware inboard of the first blade box. The results showed the cambered fairing to be superior to the symmetrical configuration. Although these results were very encouraging (ref. 7), additional research is needed to develop the proper integration of the shanks to the hub fairing for low drag.

7.0 PYLON CONFIGURATION STUDY

As previously mentioned, the pylon used in the hub-fairing configuration study was a pylon with a NACA 0034 airfoil for the cross section. This pylon cross section was selected because the first test in 1985 showed a pylon with a similar cross section to be the lowest drag configuration tested. With the NACA 0034 pylon, the 18% t/d and 8.75% cambered hub fairing was found to be the lowest-drag hub-fairing configuration. A question arises as to whether the success of the cambered hub fairing is impacted by the pylon configuration. Hence, a pylon configuration study was undertaken to survey the effect of various pylon cross sections on drag.

For the pylon configuration study, the geometry was limited by the following criteria:

1. Pylon must enclose a simulated swashplate and rotating control rods whose maximum circular-path diameter was 0.165 m (model scale).

2. Pylon would be rectangular in shape as viewed from the side.

3. There would be no gap between the pylon and the cambered hub fairing.

Based upon the above criteria, a number of pylon cross sections were designed and cross-sectional shapes categorized by two parameters, trailing-edge slope and maximum-thickness location (with maximum-thickness location ratioed to pylon chord).

The investigation into the effect of pylon trailing-edge slope on drag is presented in Figure 12a. Included in Figure 12a is a symmetrical hub fairing configuration that is comparable to the cambered hub

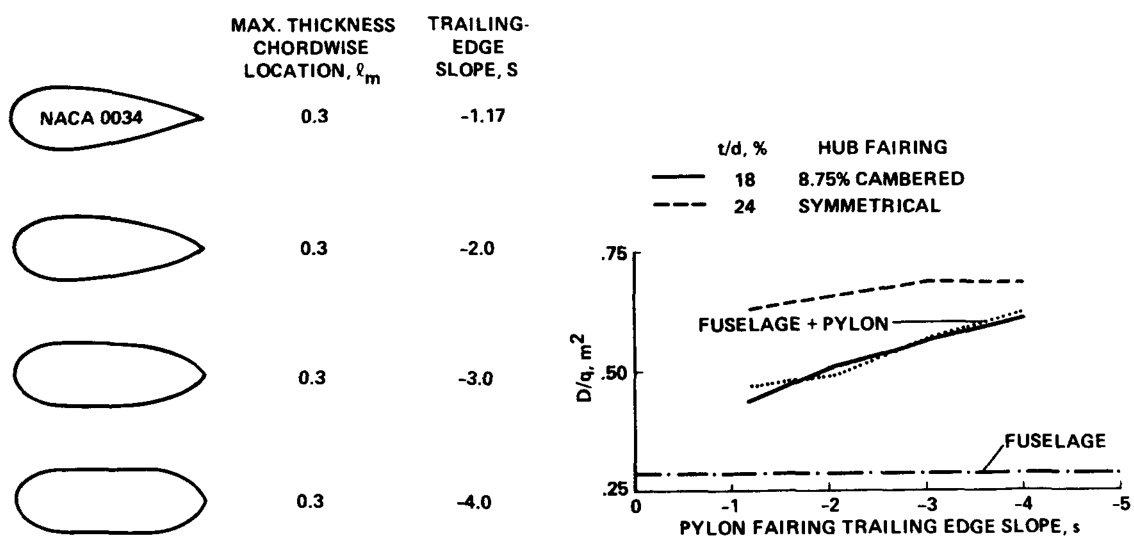

Figure 12a - Effect of pylon configuration on drag at $\alpha = -2°$.

fairing as was defined in figure 4. This comparably symmetrical fairing has a $t/d = 24\%$ with a diameter ratio of 1/1.36 to the cambered fairing diameter. The test data show the added drag from only the pylon mounted atop the fuselage is very sensitive to the trailing-edge slope parameter, s. However, the data also show that adding the cambered hub fairing produces little or no drag penalty, for all values of s over the fuselage/pylon-only configuration. On the other hand, the trailing-edge slope parameter has a more significant impact when the symmetrical hub fairing is mounted atop the pylon. At the lowest value of the slope parameter, $s = -1.17$, the drag increment for adding the symmetrical fairing is about three times the drag increment when s is its largest value. Also, the rate of change of drag with slope parameter s is much smaller with the symmetrical hub fairing than with no hub fairing. This, coupled with the fact that the drag is higher with the symmetrical fairing, substantiates an earlier finding that when a high-drag hub fairing is used, the total drag is relatively insensitive to pylon configuration. The opposite is observed when a low-drag hub fairing such as the cambered fairing is atop the pylon. With a low-drag hub fairing, the total drag is very sensitive to the configuration of the pylon.

Figure 12a also shows the pylon trailing-edge slope parameter has a major impact on the benefits attributed to the cambered hub fairing. At low values of slope parameter, the pylon drag is the lowest. Replacing the symmetrical fairing with the cambered fairing reduces pylon and hub-fairing drag increment by 50%. At $s = -4.0$, replacing the symmetrical fairing with the cambered fairing reduces the pylon and hub-fairing drag increment by only 18%. Hence, a low-drag pylon should be used with the cambered hub fairing to obtain maximum benefits of camber and to obtain the maximum drag reduction.

The sensitivity of drag to pylon maximum thickness location is presented in figure 12b. Again, adding the cambered hub fairing to the

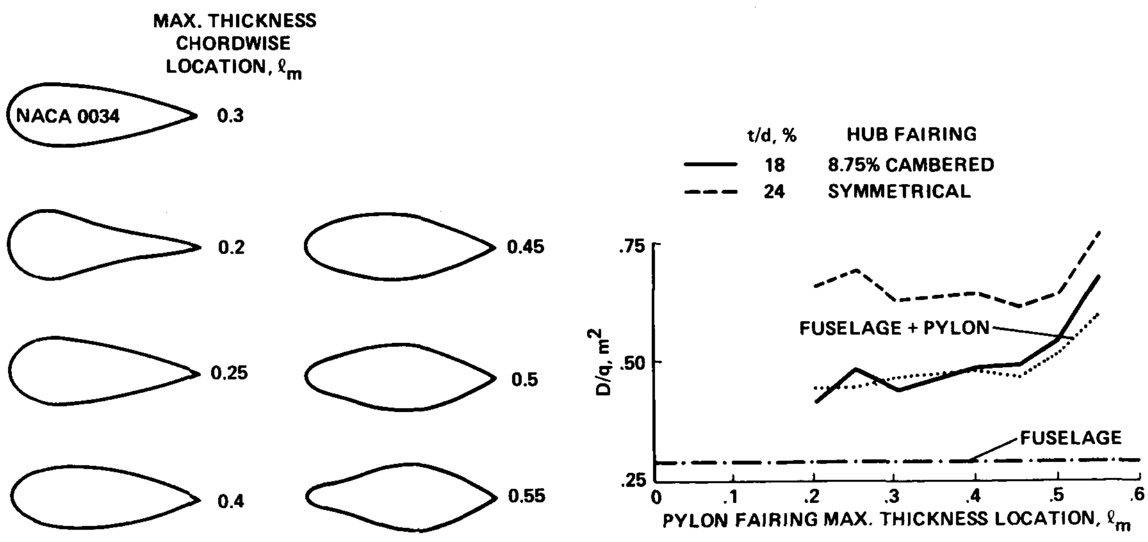

Figure 12b - Effect of pylon configuration on drag at $\alpha = -2°$.

various pylon configurations generates only a small penalty as compared to adding the symmetrical hub fairing. The sensitivity of the pylon incremental drag as a result of shifting the maximum thickness aft is relatively small until the maximum thickness is aft of the 0.45 c line. The result is a large drag increase, which is probably because the separation point is being moved progressively forward as m increases.

8.0 PYLON HEIGHT INVESTIGATION

Pylon height is a typical variable between helicopter configurations which may affect the effectiveness of any hub fairing in reducing the drag. This parameter was studied with both symmetrical and cambered hub fairing configuration atop the pylon. The results are presented in figure 13 where pylon height is nondimensionalized by effective diameter of the fuselage. The cambered hub-fairing configuration in figure 13 shows that it maintains its lower drag state compared to the symmetrical configuration for all pylon height.

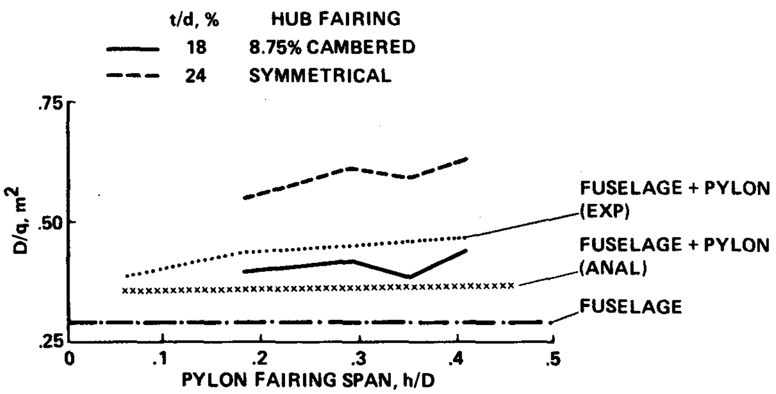

Figure 13 - Effect of pylon height on drag at $\alpha = -2°$.

Figure 13 also shows the cambered fairing drag level to be below the drag level with the hub fairings removed from the pylon for all pylon heights. It is certainly evident that the cambered hub fairing must be exerting a favorable influence on the drag. To visualize the impact of that influence, pylon drag is estimated using reference 8 and is included in figure 13. The estimated drag of the pylon is made up by pressure and skin-friction drag and a drag caused by the top edges of the pylon. The drag resulting from the pylon's top edges establishes about 80% of the drag level while the pressure and skin-friction drag provides the drag growth with increasing pylon height. The experimental drag data show drag growth at more than twice the rate of the analytically predicted growth until about $h/D = 0.18$. At greater heights, the drag growth rate is just slightly greater than the analytical rate. The high growth for $h/D < 0.18$ suggests interference effects are being produced that become stronger and stronger until $h/D = 0.18$ is exceeded. At $h/D > 0.18$, the interference effect appears to be fully established and is no longer strengthened by pylon height. This interference could be from the juncture between the fuselage and pylon or it

could be a pylon-wake influence on the aft portions of the fuselage. Further studies are required to identify the source.

The high drag produced by the top edges of the pylon would be eliminated by the cambered hub fairing with a flat lower surface. Since the estimated minimum drag of the cambered fairing is just half the drag from the pylon edges, then adding the cambered hub fairing atop the pylon should result in a drag level that is less than the pylon alone--which is so indicated by the experimental data.

9.0 EFFECT OF GAPS BETWEEN HUB FAIRING AND PYLON AND SHAFT INCLINATION

The hub fairing configuration study has shown the lowest-drag fairing is the cambered, circular arc configuration with the flat lower surface ($m = -0.62$, 8.75% camber). This study was conducted with no gap between the hub fairing and the pylon and with the hub-fairing vertical centerline at zero inclination angle. Since helicopters generally have gaps between the rotor hub and pylon, and generally have some inclination of the rotor shaft, a study was conducted to determine the sensitivity of the cambered-fairing drag level to gaps and inclination angle.

The effect of gap spacing was studied by first fixing the hub-fairing location above the top of the fuselage and then reducing the height of the pylon to create the gap. For comparison, the symmetrical hub fairing with $t/d = 24\%$ was also included in this study. Figure 14 presents the drag as a function of that gap-spacing parameter. The large drag-reducing benefits of the cambered configuration are evident only at zero gap spacing. As the gap opens up, the net drag reduction diminishes to zero at a small gap of only 14% of the pylon height and remains zero until the gap widens to 60% of the pylon height. A small drag improvement develops as the gap widens further to 100% of the pylon height. The data presented certainly shows the large sensitivity of the cambered hub fairing to gap spacing. Unfortunately, there are no test data at intermediate values of the gap-spacing parameter between zero and 0.14. Clearly the evaluation of gap spacing over this interval may be important to the viability and attractiveness of the concept.

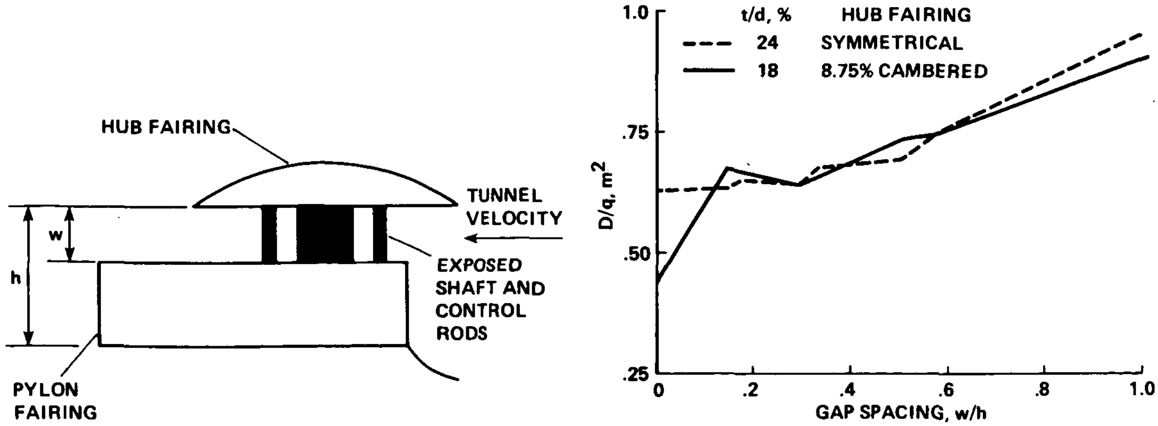

Figure 14 - Effect of pylon/hub-fairing gap on drag at $\alpha = -2°$.

One approach to eliminate pylon/hub-fairing gap but provide the blade clearance for droop and flapping is to use a thicker, cambered hub fairing. The added thickness provides the vertical clearance of the blade from the pylon. The diameter of the fairing is increased to enable continuation of the smooth surface curvature over the fairing and to enclose the drive shaft and control rods. Such a hub fairing and pylon combination is illustrated in figure 15 along with a bar graph presentation of the comparative drag data. The broken line in the large thickness-ratio hub fairing (fig. 15) depicts the bottom of the original 18% t/d hub fairing. The small drag penalty over the no-gap situation with the 18% t/d cambered hub fairing clearly makes this approach an attractive method of accommodating the blade-clearance requirement.

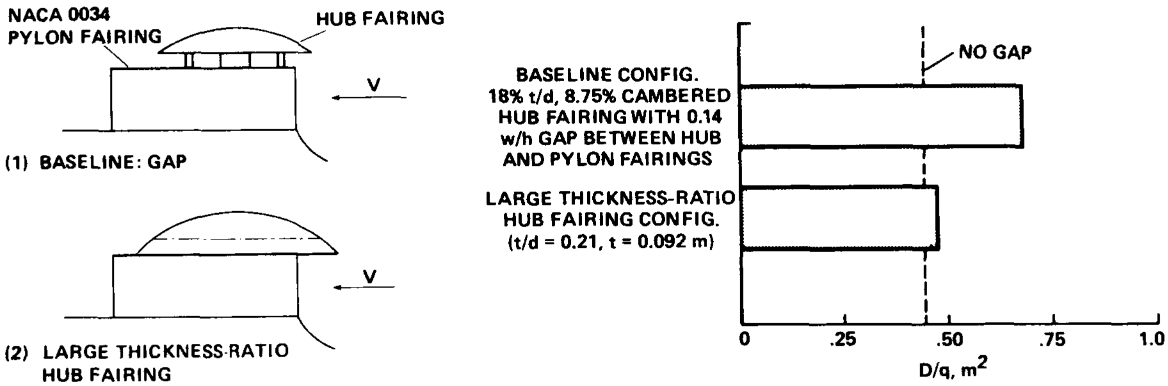

Figure 15 - Hub fairing configuration for elimination of gap spacing, $\alpha = -2°$.

To evaluate the effect of rotor-shaft inclination on drag, an inclination of -5° was selected for the sensitivity study. The configurations investigated and bar graph illustrating the drag level are shown in figure 16. For the baseline configuration, the pylon height was decreased to enable the inclined hub fairing to clear the pylon. This configuration generated considerable drag which almost doubles the drag increment for the pylon plus hub fairing. This is probably the result of considerable separation on the lee side of the hub-fairing lower surface. The high-drag situation is somewhat relieved by lowering the pylon to increase the gap. This probably relieved separation from the lee side of the fairing but the exposed shaft greatly increased the drag for a net moderate improvement over the first configuration. If the control rods were also included in the test configuration, little or no net gain may have resulted. Eliminating the gap between the hub fairing and the pylon greatly reduced the drag to about the same level as with zero shaft inclination. A disadvantage of this approach is lack of clearance for blade droop or negative flapping angle of the blades. This could be remedied using the dual component fairing shown in figure 16. The dual component fairing has greater frontal area; hence, it causes a larger D/q for a net result that is only about 10% greater than with the noninclined shaft configuration.

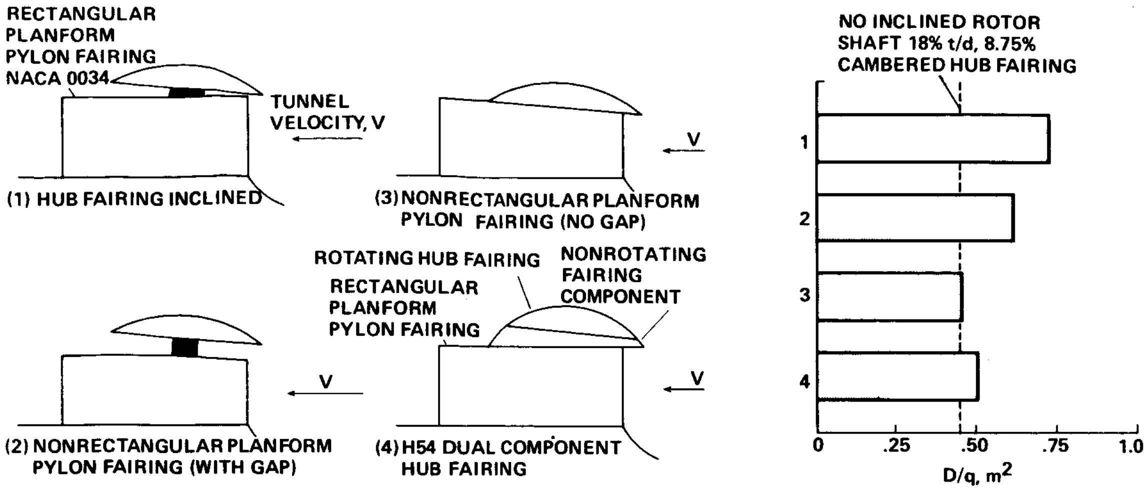

Figure 16 - Pylon and hub-fairing study for shaft inclination, α = -2°.

10.0 ADDITIONAL FUTURE RESEARCH

The drag reduction achieved by the cambered, flat-bottom hub fairing is very encouraging. Additional research is anticipated and planned for further exploitation of the concept, and to develop the understanding of the technology that achieve these kinds of attractive results. Future research will include:

1. Integration of blade shanks with the hub fairing and pylon fairing into a low-drag configuration appropriate for future helicopters.

2. Effects of rotation.

3. Investigations to understand and control the aerodynamic phenomena that are involved in achieving the low-drag configuration.

4. Development and validation of the computational codes that may be useful tools for future designs.

With the encouraging and attractive benefits of the cambered hub fairing and with continued research, the 50 to 80% reduction in hub drag may be an achievable goal.

11.0 CONCLUSIONS

Ames Research Center has been conducting a research program to develop the technology to substantially reduce helicopter hub and pylon drag. The following are the major observations based upon results of the investigations.

1. Hub fairing camber is effective in reducing drag. When compared to a symmetrical configuration, the most effective camber results in a flat lower surface.

2. A circular arc, upper-surface curvature provides the lowest drag of hub-fairing configurations with a flat lower surface.

3. Gaps between the pylon and the cambered hub fairing negate the benefits from the cambered, flat lower surface. The high-drag, symmetrical hub-fairing configuration was less susceptible to drag increases from gaps. A low-drag alternative configuration is a cambered, flat lower-surface hub fairing with thickness increased to provide the necessary spacing between blade and pylon.

4. Total drag was less sensitive to pylon drag when a symmetrical hub fairing was used in place of the cambered hub fairing. This is attributed to the high drag resulting when the symmetrical fairing is atop the pylon.

5. A large portion of the drag reducing benefits of the flat-bottom cambered hub fairing over the symmetrical configuration is attributed to a) elimination of separated flow between the hub fairing and the pylon and b) elimination of the eddy shed from the upper corners of the pylon.

6. Additional research is required to transform the cambered, hub-fairing concept into an attractive low-drag design.

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16. Abstract

This paper reports investigations of fairing configurations pointed toward substantially reducing hub drag. Experimental investigations have shown the importance of hub-fairing camber, lower-surface curvature, and relative size on the drag. The significance of pylon and hub fairings in combination have also been shown. Model test data presented here documented these findings, and also showed the effect of gaps and hub-fairing inclination angle on drag. From a drag standpoint, the best hub fairing had a circular arc, upper-surface curvature, a flat bottom surface, and 8.75% camber.

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